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Multisensor Image Analysis System

Final Report

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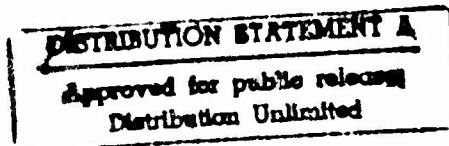
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April 15, 1993

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13. ABSTRACT (Maximum 200 words)

The research sponsored by this grant is focused on the development of robust scene analysis algorithms to reliably analyze complex scenes with widely varying environmental and countermeasure conditions. Hybrid digital/optical processing architectures are developed to assimilate large quantities of multisensory information to locate and recognize targets in cluttered scenes. The major contribution of the research is the development of a theoretical and technological basis for designing robust multisensory vision systems.

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I. STATEMENT OF RESEARCH PROBLEM

Much research and development effort has been devoted to create smart weapon systems capable of detecting air and ground targets in widely varying hostile environments. It is generally accepted that currently available multispectral sensor technology (infrared, visible, ladar, millimeter wave) provides sufficient information to develop robust vision systems that perform reliably in complex scenes with widely varying environmental and countermeasure conditions. This acceptance, however, is often based upon the ability of a human observer to perform the visual tasks using the sensory data. The basic problem is to select multiple sensors/features that provide sufficient information to allow the development of robust algorithms that can resolve the complexities introduced by dynamic environmental and countermeasure conditions. Robust multiple sensor/feature processing algorithms to distinguish target signatures, however, have not demonstrated the ability to reliably distinguish signatures in widely varying hostile environments. The result has been the development of a large number of algorithms that work only in very limited conditions. Much effort is spent trying to modify these algorithms to work in a larger classes of environments. These efforts have generally been unsuccessful due to the fact that there is no validated theory for adaptively selecting and fusing the distinguishing features in terms of the large number of environmental and countermeasure attributes that exist in real battlefield environments. Furthermore, these algorithms do not utilize the important physical principles of the atmosphere and countermeasures to distinguish target and background signatures.

The research sponsored by this grant is focused on two important technical barriers that inhibit the development of robust vision systems. These are:

* Robust scene analysis algorithms to reliably analyze complex scenes with widely varying environmental and countermeasure conditions.
* Real time processing structures to assimilate large quantities of multisensor information to make optimum decisions.

The primary objective of this research grant is to develop a theoretical and technological basis for overcoming these barriers. Our approach to these barriers is to develop mathematical methods to evaluate and fuse multisensor features to analyze complex scenes using hybrid optical/digital processing techniques. Rapid evaluation of individual and multiple sensor performance together with effective sensor fusion are essential capabilities. Intelligent vision systems must quickly analyze dynamic visual scenes and produce intricate non-linear control strategies. These tasks are complicated by the fact that the sensory information is often uncertain, incomplete and even contradictory.

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II. SUMMARY OF RESULTS

The research performed during this grant is focused on the development of mathematical foundations for designing robust multisensor vision systems. Emphasis is placed on four major research areas. These are:

* Electronic Vision/Image Processing
* Electro-Optical Processing
* Vision Systems/Intelligent Control
* Multiprocessor Vision Architecture

The first area concerns image processing functions for fusing, detecting and recognizing objects of interest in multisensor image sequences. The second research area concerns the advancement of electro-optical processing techniques and integration with digital processing techniques to detect and recognize objects. The third area involves the development and testing of a control model to support the development of intelligent control algorithms. The last area involves the development of a methodology for designing and evaluating multiprocessor architectures for real time vision systems.

2.1 Image Processing Research

The thrust of the image processing research is to develop mathematical/engineering foundations for designing and evaluating multisensor vision systems capable of performing in widely varying and hostile environments. The major accomplishments of this research effort are:

* Theoretical foundations and algorithms were developed for evaluating the complexity [1] of vision tasks in terms of the information content of multisensory inputs. This allows sensors and features to be designed to reduce the complexity to meet design specifications.

* Statistical measures [2-5] were established for evaluating the performance of multisensor features in terms of their ability to distinguish target and background signatures. These measures are effective indicators of performance in high-dimensional sensor/feature spaces.

* A laboratory environment [31] was developed for integrating optical and digital processing concepts. Optical and digital image processors have been successfully integrated, resulting in a high speed hybrid optical/digital scene analysis system that combines the speed and massive parallelism of optical processors with the flexibility and statistical decision-making capability of digital processors. The vision system utilizes a large field-of-view camera to locate objects of interest and direct a high resolution color camera to segment

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and recognize objects in a cluttered background scene. Optical processing techniques perform the intensive computational tasks associated with locating and recognizing objects of interest. Currently, the prototype system can recognize any one of nine similar objects placed at any position and orientation on the NMSU terrain board.

* An adaptive "neural-like" decision module [10] was developed for making fast and near minimal probability of error decisions in high dimensional sensor/feature spaces. Using this decision module, robust algorithms were developed for target detection, segmentation and identification. These algorithms are incorporated in our optical/digital electronic vision system and have demonstrated robust performance in complex scenes.

* Significant progress has been achieved in developing a common mathematical foundation for the comparative analysis of statistical, fuzzy logic, and artificial neural network pattern recognition systems [12]. Practical applications of this theory can combine previously disjoint disciplines into hybrid pattern recognition systems that can rapidly learn and adapt to changing environments.

* Researchers at NMSU and the Atmospheric Sciences Laboratory (ASL) are jointly investigating the effects of atmospheric and field conditions on sensor/feature performance [13,14]. Atmospheric turbulence phenomena in the long infrared have been isolated in data obtained by the ASL Target Contrast Characterizer. Significant progress has been made in developing and validating turbulence models with the field data. The goal of this cooperative effort is to develop new techniques for processing infrared imagery degraded by atmospheric turbulence and ultimately to develop new systems with significantly improved performance.

2.1.1 Complexity of Vision Tasks

A fundamental problem in the design of vision systems is to assess the level of difficulty associated with performing the required tasks with the sensor information available. A doctoral dissertation [1] was associated with developing effective measures to establish task complexity in terms of sensor/features. These complexity measures were developed in terms of a random process model of the scene environment as viewed by the sensor array. The complexity measures are all developed in terms of optimal performance levels for statistical decision rules, and therefor provide achievable bounds on system performance. The measures can be used to evaluate and select features and algorithms based on their effectiveness in the decision-making process. Theorems and proofs establish important and useful properties of the measures and relate them to other known performance measures. These

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measures have been widely used to evaluate the effect of countermeasures and atmospheric disturbances on sensor/feature performance.

2.1.2 Information Fusion

Two doctoral dissertations [2,3] were associated with developing a mathematical basis for evaluating and fusing sensory information for optimal decision processes. Effective methods were established for evaluating the performance of multisensor features in terms of their ability to distinguish target and background signatures. A statistic, called the tie statistic, was introduced [2] and developed as a measure for distinguishing two probability density functions. Theorems and proofs establish important relations between the tie statistic and the Kolmogorov-Smirnov measures. Through these relations, the tie statistic is related to other popular discriminating measures such as the Matusita distance, the Bhattacharyya coefficient and the divergence measure. The tie statistic can be used to transform a feature space to an ordered space with simplified decision boundaries. The mapping process uses the tie statistic to measure differences between probability density functions of features. Hence, the new tie space can be used to evaluate the difficulty associated with distinguishing signatures in high dimensional feature spaces. Necessary and sufficient condition were established [3,4,5] for using the tie statistic to fuse multisensor date into a single signal without increasing the complexity of the vision task. Algorithms were developed [4,6] to perform information fusion, texture recognition and target cueing in multisensor scenes.

2.1.3 K-Nearest Neighbor Signature Analysis

The k-nearest neighbor concept [7] was used to develop a measure for evaluating the difficulty associated with distinguishing signatures in high dimensional feature spaces. The new measure, called the k-complexity, combines the complexity measures [1,2] and the k-nearest neighborhood concept to provide an effective method to estimate the minimum probability of error associated with distinguishing target signatures. The major advantage of the k-complexity is that it can be computed without estimating the joint probability density functions. This is particularly important for multispectral signature analysis where the number of sensors/features of interest can be quite large. Efficient software modules have been developed to compute the k-complexity and experiments have demonstrated its potential.

The k-complexity measure is defined in terms of the k-nearest neighborhood concept often used for estimating probability density functions. Given two sets of signature measurements

$T = \{ X : X = (x1,x2,\ldots,xN) \text{ target feature vector } \}$
$B = \{ X : X = (x1,x2,\ldots,xN) \text{ background feature vector } \}$

each with NS samples that characterize the target and background

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signatures, respectively. Considering the T and B samples as points in an N dimensional space, the k-nearest neighborhood set, KNN(X), is defined as the k-nearest points to X in the set T ∪ B. A discrete random variable Y is defined as the number of points in the intersection of KNN(X) and T, i.e.,

$$Y = \text{order}(KNN(X) \cap T) \qquad Y \in \{0,1,\ldots,K\}.$$

The conditional probability density functions $f(y:X \in T)$ and $f(y:X \in B)$ are defined as the probability of observing y given that X came from T or B, respectively. Letting Pt and Pb define the a priori probabilities of target and backgrounds observations, the k-complexity is defined by

$$KC = \frac{1}{(P_t \wedge P_b)} \sum_{y=0}^{K} P_t f(y:X \in T) \wedge P_b f(y:X \in B) .$$

where the operator $\wedge$ selects the minimum. It is important to observe that the K-complexity is defined in terms of single dimensional pdf's, making it computationally attractive for estimating the effectiveness of multi-dimensional feature vectors. The k-complexity varies from 0 to 1 and measures the level of difficulty associated with detecting whether the measurements came from a target or from the background. If the k-complexity is a zero then there is little or no chance of confusing target and background measurements. On the other hand, if k-complexity is one then there is an even chance based on the measured features that the measurements came from a target or background.

Several important theorems [8] have been established to give the k-complexity measure credibility. If the likelihood ratio of the target to background is a constant in the hyper-spheres defined by KNN(X), then the k-complexity is directly related to the minimum probability of error (MPE) given by MPE = 0.5*KC. Furthermore, in constant likelihood ratio case, the k-complexity approaches the complexity defined in terms of the joint probability density functions and is independent of k. Experimental results [9] have shown that good estimates of k-complexity are obtained with very reasonable sample sizes. The direct relation between the k-complexity and MPE along with the fact that good estimates can be obtained with relatively small samples, motivated the development of the k-complexity to form a basis for measuring the effectiveness of multispectral feature vectors in distinguishing target signatures in CM environments.

2.1.4 Adaptive Decision Module

An adaptive "neural-like" decision module [10] was developed for making fast and near minimal probability of error decisions in

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high dimensional sensor/feature spaces. New algorithms for clustering high dimensional multisensor data and modeling the clusters with extended k-nearest neighbor concepts have been developed. The theory of k-nearest neighbor concept has been extended to generate quadratic surfaces by weighting the points. Any quadratic surface can be realized with only two control points. Adaptive algorithms have been developed to locate the control points and weights to realize multisensor decision surfaces. Using these concepts, several new algorithms for target detection and identification have been incorporated in a demonstration optical/digital electronic vision system. The new algorithms have demonstrated robust performance in cluttered scenes.

The adaptive decision module [10] has been used to perform complex and nonlinear control functions. A training procedure is used to generate a finite set of control points in the state space that define the control law. The controller has been used to balance an inverted pendulum mounted on a moveable cart and to remotely position a trailer truck to a specified position in a constrained region using a video tracking system. These problems demonstrate the power and simplicity of the nearest neighbor controller in nonlinear systems. To demonstrate the concepts, a vision guided system was developed to remotely park a truck-trailer in a constrained region. The control structure adapts well to random effects caused by measurement and vehicle control errors and is suited for nonlinear and unstructured control problems that are difficult to model.

2.1.5 Mathematical Foundations for Pattern Recognition Systems

A common mathematical foundation for the comparative analysis of statistical, fuzzy, and artificial neural pattern recognition or decision making systems was developed [12] using abstract algebraic techniques to characterize the functions generating decision surfaces and the learning/training processes involved in each technique.

Abstract algebra is built on the most basic of foundations: sets, operations on sets, and mappings from set to set. Viewed from this level, all pattern recognition methods are strikingly similar. So much so, that a generalized pattern recognizer (GPR) can be defined such that all others are its subsets or special cases. The basic structure of the GPR was developed during this project. Typical popular statistical, fuzzy, and artificial neural pattern recognizers were characterized in the context of the GPR [12]. Each of the modern methods has strengths and weaknesses, advantages and disadvantages. Using the concept of a GPR, it is possible to design and build hybrid systems that capitalize on the advantages and strengths of all previous methodologies. Each of the modern pattern recognition areas has its own terminology and set of notations. As much as possible, the standard notation for each discipline was preserved and described in its relation to the

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standard notation of abstract algebra.

The study of pattern recognition has many important goals among them are the development of methodologies for designing and building machines capable of recognizing and learning to recognize objects in natural or unstructured environments. The common task of any pattern recognizer is to obtain a set of observations or measurements from an unknown (or unclassified) pattern and to decide which class the pattern belongs based on the values observed. From an abstract point of view, once pattern recognition is clearly defined within a mathematical framework, the pattern recognition task becomes simply a mathematical problem.

A pattern recognizer is a decision maker or *decider*, D, that can be viewed as a mapping from an arbitrary observation space M to a finite set of symbols representing decisions or object classes, Ω. D is therefore a triple (M,Ω,δ) with M, a space (a largest set from which subsets of observations are taken), Ω, a finite set of symbols, and δ, a mapping from M to Ω, $\delta:M\to\Omega$. The decider is meaningful only if Ω contains two or more elements and M contains at least as many elements as Ω. For most deciders, the mapping δ is many-

Fig. 1 Conceptual view of abstract pattern recognizer.

to-one with the number of elements in M quite large, often not finite. In these cases, the mechanism creating δ defines a partition of M with non-overlapping subsets of M mapping into elements of Ω. Note that members of the special subset of deciders characterized by finite M are called combinatoric machines in automata theory with M being a finite set of input symbols and Ω a finite set of output symbols [10].

There are three basic types of deciders: fixed, trainable, and learning. The mapping δ in a fixed decider is static. It is developed prior to the use of the decider and does not change during decider operation. The trainable decider has a training mode wherein the mapping can be altered in response one or more sets of measurements whose classification is known a priori. The mapping of a learning decider develops and evolves as the decider encounters and classifies new patterns of unknown classes. There are, of course, many variations of these basic types.

Irregardless of the type or implementation method, all pattern recognizers are *deciders* as defined above. Once a specific pattern recognition task has been defined, the sets M and Ω are the same whether the pattern recognizer be classical deterministic,
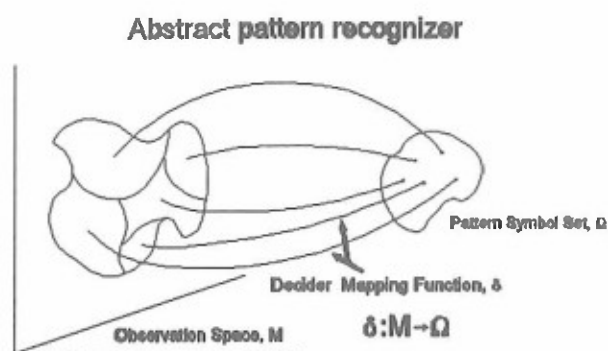
statistical, fuzzy, artificial neural, or something altogether new. What differs for each is the mapping δ and its generation. For typical examples of each of the pattern recognition methods chosen for comparative analysis, the composition of δ is derived and used as a basis for comparison and contrast. In each of these methods, the mapping δ is expressed as a composition of a decision rule and another set of mappings classically termed discriminant or decision functions. The three methods chosen for analysis are also based on the implicit assumption that M and the subsets of M from which measurements are taken is a measurable space. In this development, M was arbitrarily restricted to be a vector space.

These restrictions were for convenience only and are not contained in the fundamental definition of a decider. Without these restrictions, extraordinarily rich pattern recognizers can be developed using non-measurable spaces containing measurable subspaces. The use of a non-measurable space M provides a mechanism for incorporating non-measurable information dimensions and non-measurable a priori knowledge into a pattern recognizer. This important extension was beyond the scope of the present work and was left for future research.

2.1.6 Effects of Atmospheric Phenomena on Sensor Performance

Modern high resolution infrared (IR) sensors are instrumental in advanced systems for automatic detection and recognition of interesting objects in cluttered backgrounds along relatively long (1-2km) horizontal paths. The thermal sensing component of a Automatic Target Recognizer (ATR) is called upon to assist in locating regions containing objects or targets of interest, separating the objects from the background, classifying objects and background scenes, and making control decisions. These tasks are commonly referred to as the cuer, segmenter, recognizer, and controller respectively. The design of these processes begins by selecting a set of sensors and features that can distinguish object versus background signatures. Typically, the selection of sensors and features is based on models of physical properties of the objects and backgrounds of interest. The goal is to remotely sense and extract sufficient information to distinguish object and background signatures in widely varying environmental conditions. Algorithms based on statistical, syntactical, or spatial frequency techniques are in common use. The IR components of such systems are plagued by a number of atmospheric effects that cause degradation in the sensed images driving the automatic detection and recognition algorithms.

Researchers at NMSU and the Battlefield Effects Directorate of the Army Research Laboratory (formerly the Atmospheric Sciences Laboratory) have been investigating and characterizing these effects throughout most of this research project [13,14]. The scene degrading atmospheric effects fall into three broad categories: 1) reduction in object contrast with respect to

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background clutter caused by changes in energy emissions from either the object, the background, or both. 2) reduction in object contrast with respect to background clutter caused by absorptive, radiative and scattering effects along the path of propagation. 3) blurring and distortion of object details caused by scattering and inhomogeneities in the refractive index along the path of propagation.

The cueing task involves imaging a relatively large field of view (FOV) to find regions that have a high probability of containing an object of interest. For any imaging system with a fixed number of resolution elements, FOV and spatial resolution are inversely related. A large FOV implies low spatial resolution and vice versa. The cueing algorithm directs the attention of the segmenting and recognizing tasks, allowing them to operate on images with much smaller FOVs and consequently much higher spatial resolutions with respect to an object's fine details.

Because of the relatively lower spatial resolutions, ATR cueing algorithms rely mostly on contrast measures and a priori knowledge of typical object sizes. Very little textural and structural information is available. The segmenting and recognizing algorithms, on the other hand, rely mainly on textural and structural properties of an object versus background. Degradation of contrast tends to have a large effect on cueing, while blurring of edges and structural details tends to affect segmenting and recognizing. As atmospheric phenomena can affect both contrast and definition, it is important to characterize these as much as possible to aid in predicting ATR performance under varying conditions.

Throughout this project, data useful for detailed characterization of the degradation phenomena in each of the three categories was collected and analyzed using the U.S. Army Research Laboratory's Mobile Imaging Spectroscopy Laboratory (MISL) with its Target Contrast Characterizer (TCC)[4]. The MISL/TCC consists of: 1) two Inframetrics model 610, moderately high resolution, IR imagers; 2) two Sony model DXC-102 visible wavelength color CCD television cameras; 3) a Recognition Concepts, Inc. real time image processing system; 4) a computer controlled meteorological station; 5) a Lockheed Model IV-L atmospheric scintillometer; 6) a large area blackbody source; 7) video recording equipment; 8) miscellaneous lenses, telescopes, and other optical components. A typical system set-up is shown in Fig. 2.

The IR imagers are cryogenically cooled, scanning single detector units with independent electronic control over the horizontal and vertical scan deflection factors. Each imager has two channels operating simultaneously at wavelengths of $3-5\mu m$ and $8-12\mu m$. The meteorological station logs temperature, barometric pressure, relative humidity, wind velocity, and solar flux at one second intervals. A large, highly uniform, blackbody source with

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BLACK BODY

OBJECTS
BACKGROUND

ATMOSPHERIC EFFECTS

MET. STATION

IMAGERS

IR1 IR2 V

IR1 IR2 V

CPU

IR1 - 3-5 μm INFRARED
IR2 - 8-12 μm INFRARED
V - VISIBLE

IMAGE PROCESSING
SYSTEM
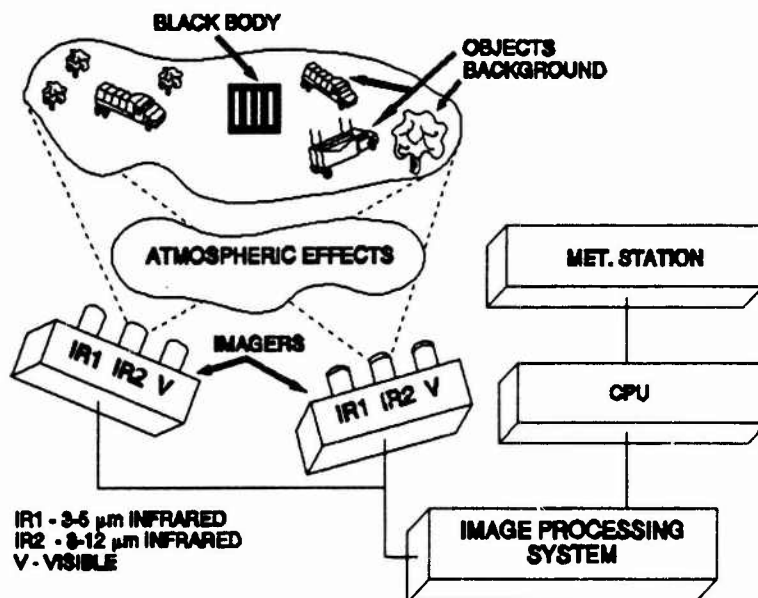
Fig. 2 Typical MISL Experiment

removable spatial patterns is used in a number of the experiments. The unique device has a 1.78m x 1.78m effective surface area with a novel tilt-back design and non-uniformly spaced heater configuration that eliminates the vertical temperature gradients and convection cell separations typical of large vertical sources. The design includes shielding from solar loading and wind. The separation of the pattern panels from the source gives nearly perfect transitions between the hot and cold portions of the patterns.

Many of the theoretical techniques developed in other areas of the ARO Electronic Vision Research project were applied to the actual field collected data to assess their practical utility with respect to the U.S. Army's "real world" problems. Several of the concepts proved to be extremely useful. Complexity and k-complexity, in particular are efficient and robust measures for quantifying contrast degradations due to both inherent scene and path environmental effects.

2.2 Electro-Optical Processing

The goals of the electro-optics group were (1) to assess the state-of-the-art of optical processing technology, (2) to develop a mathematical foundation for designing practical optical processors, and (3) to advance the state of technology by developing and integrating optical processors with digital systems to improve system performance in the areas of monitoring, cueing, segmenting, recognizing and/or tracking targets of interest.

The significant contributions of the electro-optical

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processing research are summarized by listing the most significant accomplishments.

*   Established long-term associations with the leading U.S. researchers in optical image processing and pattern recognition.

*   Produced the world's first (a) real time magneto-optic spatial light modulator (MOSLM) software driver, (b) real time hybrid optical/digital correlator using MOSLMs as input and filter transducers, (c) ternary phase-amplitude filters written on the MOSLM.

*   Developed and tested a short coherent optical correlator architecture using pixelated spatial light modulators and identified the practical limitations of optical correlation system miniaturization.

*   Adapted the correlator design so that inexpensive liquid crystal television displays (LCTVs) can be used as input and filter transducers capable of continuous modulation of either amplitude or phase.

*   Produced ternary phase-amplitude synthetic discriminant function composite matched filters that are written at high speed (up to 300 frames per second) onto a MOSLM filter transducer to achieve scale, rotation, and aspect invariant recognition.

*   Developed a correlation plane filter which performs a Bayes likelihood ratio test on the correlation responses from composite matched filters arranged in a N-dimensional decision tree to perform efficient and reliable object recognition.

*   Developed, built and demonstrated a prototype optical/digital recognition system that can recognize segmented images of any one of nine objects placed at any position and orientation on the NMSU terrain board within one second with a measured correct recognition rate of 81.16% and a false alarm rate of 2.4%.

*   Demonstrated a real time LCTV-based optical cuer that locates targets of interest in a large field-of-view gray scale image.

*   Identified several future applications of optical image processors in areas such as biomedical imaging, forensics, security, air traffic control, and defense.

2.2.1 Assessment of Electro-Optical Processing Technology

During the first year our efforts were focused on establishing the frontiers in optical processing technology. Several visits

were made to several leading university and government laboratories with active research programs in optical processing, intensive literature searches were completed, and several conferences on the subject were attended. Perhaps, the most valuable accomplishment of that first year was the establishment of long-term associations with leading research personnel working on electro-optical processing projects at key laboratories throughout the United States. A second major accomplishment was the interfacing of a digital frame grabber to a magneto-optic spatial light modulator (MOSLM) and the development of the world's first real time software package that allowed images from a TV camera to be digitized, binarized, and then displayed on the MOSLM in real time (30 frames per second) [15].

2.2.2 Hybrid Optical/Digital Real Time Correlator

Having established valuable continuing technical interactions with government laboratories and developed a powerful tool for real time optical processor development (real time software to drive the MOSLM) during the first year (1987), the group's attention shifted to the development of a real time hybrid optical/digital correlator during the second year. The mathematical foundation for such a system was developed, the system was built [16] using 128x128 MOSLMs at the input and filter planes, and the efficiency of the system was optimized. This system was the world's first real time 128x128 MOSLM-based binary phase-only sequential correlation system. One other researcher (Flannery [17] at the University of Dayton) had developed a similar correlator that used 48x48 MOSLMs at the input and filter planes to produce static (every few seconds) binary phase-only image correlations, and three other researchers (Ross [18] at Litton Data Systems, Davis [19] at San Diego State University and Psaltis [20] at CalTech) had used the MOSLM as a binary phase-only filter with film at the input plane, but the NMSU system was the first to incorporate 128x128 MOSLMs at both planes and to operate in real time. Ross and associates at Litton, working independently and without knowledge of our work (and vice versa), built a similar real time system that same year (1988). NMSU and Litton began technical interactions during 1989.

Three other major accomplishments highlighted the work of 1988: (1) the MOSLM frame rate was increased to 80 frames per second, (2) time-sequenced filtering and statistical correlation plane processing techniques were developed to process sequential correlation plane data and recognize multiple input objects at any in-plane rotation [15], and (3) the world's first ternary phase-amplitude filters [21] were written on the MOSLM and demonstrated in NMSU's electro-optics research laboratory. These filters significantly improved the signal to noise ratio of output correlation responses.

During 1989 the research focussed on the following goals: (1) increasing the speed of operation of the MOSLMs, (2) achieving

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invariance to any number of image distortions including aspect, scale, and in-plane rotation, and (3) reducing the physical size of the optical correlator. The MOSLM frame rate was increased to 300 frames per second, and a rotation, aspect, and scale-invariant object recognition system was demonstrated using time-sequenced filtering and statistical correlation plane processing [22,23]. A time-integrating rotation-invariant image correlator was also developed that integrated the correlation responses of sequential simple filters [24]. This system took advantage of the high frame rate of the filter MOSLM to obtain integrated composite responses that were then analyzed statistically to recognize objects of interest. The third goal was realized with the development and demonstration of two miniaturized optical correlators--one using 128x128 MOSLMs and the other using 48x48 MOSLMs at the input and filter planes [25].

2.2.3 Hybrid Optical/Digital Target Recognizer

In 1990 the NMSU terrain board was built, and an optical processor was developed to perform the target recognition task, while digital processors were developed to perform the target cueing and segmentation tasks. The goals for 1990 were (1) to build and characterize two time-integrating correlators using high-speed output cameras to realize the advantage of such systems--one used a Xybion CID output camera and the other used a Reticon CCD output camera [26,27], (2) to simulate the use of Texas Instruments' deformable mirror devices (DMDs) in the optical correlator [28], (3) to complete the study of short optical correlators, (4) to develop software to create composite binary phase-only filters that are invariant to all distortions of objects placed at any position on the NMSU terrain board [29], and (5) to develop an efficient search strategy using composite binary phase-only filters to achieve distortion invariant recognition of objects at any position on the terrain board. All of these goals were accomplished, and the optical recognition system was used to recognize selected segmented objects imaged from arbitrary positions and orientations on the terrain board. The search strategy selected was a binary tree search of composite binary phase-only filters [29].

The goals for 1991 were (1) to demonstrate a working recognition system in an automatic mode using the terrain board as the input scene, (2) to complete the study of the practical limitations of optical correlation system miniaturization and to build and test several systems, (3) to obtain binary phase-only correlations of input gray level images using a liquid crystal television (LCTV) as the input gray level image transducer, (4) to develop an optical cuer using LCTVs at both input and filter planes of the optical processor, and (5) to identify new applications for the optical processing technology developed at NMSU and to perform preliminary experiments in these application areas.

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The first goal was met by developing a statistical recognition algorithm based on a Bayes likelihood ratio test [30,31]. The test was applied at each node of an N-dimensional tree of composite binary phase-only filters in order to facilitate the correct traversal of the tree, correct recognition of known objects and correct rejection of unknown input objects. An empirical synthetic discriminant function method [32] was developed which produced composite filters with nearly equal correlation peak responses over the desired span of distortions. These filters were used at each node of the tree with filters covering the largest distortion invariant span at the top and becoming less composite and more specific as the tree was traversed from top to bottom. Several short optical correlators were designed, built and evaluated [33] in order to complete the second goal. The third and fourth goals were accomplished by designing and building an optical spatial filtering system with LCTVs at both planes and then developing and testing matched binary phase-only filters for correlation and size-selective gray scale amplitude filters for cueing [34]. New applications that were identified and pursued include correlation tracking of tissue motion and blood flow in ultrasound images [35] (biomedical) and fingerprint classification (forensic).

2.2.4 Bayesian Likelihood Classifier

During the final year (1992) the electro-optical processing group concentrated on (1) the completion and final testing of the Bayesian likelihood classifier used for object recognition, (2) the use of LCTVs in correlation and spatial filtering systems, and (3) improved preprocessing of input gray level images using spatial filtering to locate objects of interest.

After detailed analysis and testing of several statistical classifier algorithms, the composite Bayesian likelihood classifier was shown to give the best performance [36,37]. This classifier exploits the gaussian behavior of correlation plane response data and is able to concisely represent multimodal distributions (obtained by superposing many normal distributions from thousands of training set responses used as calibration data) as composite algebraic functions and then use those distributions to partition the vector signal space into classification regions derived from Bayes' likelihood ratio test. The expected performance of the classifier was calculated and then compared with the actual performance obtained using as inputs actual training images chosen at random. The predicted overall correct classification rate was 99.76%, and the measured rate for 36,000 tests of randomly chosen training image inputs was 99.21%. The overall correct classification rate of terrain board images (not training images) was obtained using 233 images of a 9 member target class and 84 images of 5 nontargets with shapes resembling some of the target class members randomly placed at locations covering the full extent of the terrain board. The terrain board test yielded an overall hit rate of 81.16% and a 2.4% false alarm rate.

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LCTVs were characterized and used to produce several types of filters including matched binary phase-only filters, gray scale apodized amplitude filters, and amplitude weighted binary phase-only filters. LCTVs were also used to produce gray scale input images to test each of the filtering operations. A real time target cuer was built [38] and used successfully to locate targets of interest in a large field-of-view gray scale image using size-selective spatial filters with Hanning apodization to reduce the ringing in the filtered output images. The inputs and filters were written to LCTVs, and the output bright spots corresponding to the detected targets of interest were acquired with a CCD camera.

2.3 Multiprocessor Vision Architecture

The goal of the multiprocessor architecture research is the development of a methodology for designing and evaluating multiprocessor architectures for real time vision systems. The major accomplishments of this research effort are:

* Discovery of a virtually unexplored class of multiprocessor architectures whose members exhibit superior performance for many real time weapon systems and battlefield management tasks, including multisensor vision. This class of multiprocessors employ global memory for high speed computations, and message passing for modularity, reliability, and scalability [11].

* Design and construction of a prototype Virtual Port Memory machine [12] that supports the global-memory and message-passing architecture. Evaluation of this machine has confirmed the performance predicted analytically.

* Development of the ARGOS multiprocessor operating system for Global-Memory Message-Passing architectures.

* Establishment of the Parallel Architecture Research Laboratory for studying the theory and design of multiprocessor and distributed architectures.

* Development of a theoretical model of parallel systems that predicts system performance based upon nearly independent models of architectures and algorithms.

2.3.1 The Virtual Port Memory Machine

Our contributions to the field of multiprocessor hardware design include the development of the prototype Virtual Port Memory machine, and the evaluation of related ideas in processor and system architecture.

The Virtual Port Memory (VPM) machine was built specifically

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to evaluate the novel idea of supporting a message passing parallel environment using a global memory hardware structure [39]. This unusual combination provides the modularity and scalability of message passing, while using a shared global memory to provide uniform high-speed access to the large data structures found in computer vision. Because process address spaces are strictly private in the message passing paradigm, processors are free to employ very large cache memories to improve system performance, without a requirement to maintain cache consistency [40].

Analysis and simulation of a prototype design indicated that such a machine (using CISC processors) would scale to 256 processors on a single bus, and provide higher performance than other architectures using similar technology. To test these predictions, we built a small prototype machine, and wrote a POSIX-compliant operating system for it (ARGOS, described below).

Gaussian elimination was chosen as an initial vehicle for evaluating the performance of the VPM prototype, due in part to the availability of published data for the performance of both message passing and shared variable versions of this algorithm on the BBN Butterfly multiprocessor. A message-passing version of the algorithm was written in C for the VPM prototype, and its execution on a single processor was measured using the facilities of the Parallel Architecture Research Lab (PARL) at NMSU. These detailed measurements were then used in a simulation of VPM machines with up to 128 processors (the maximum number of processors in the Butterfly results), and various analyses were performed on the simulation results.

These results confirmed our earlier analytical predictions of linear speedup for VPM machines with over 100 processors, even when a bus is used as the processor-memory interconnection network. The speedups achieved with the 800 x 800 Gaussian elimination on the VPM machine matched the theoretical maximum speedup available from the algorithm, while the Butterfly speedups fell far short of those theoretically achievable due to memory and interconnection network contention [48].

In addition to the advantages of the Virtual Port Memory multiprocessor architecture for such computation-intensive tasks as Gaussian elimination, we have found it well suited for the I/O intensive tasks of computer vision, as well as for such similar I/O intensive applications as processing space telemetry packets (which are expected to arrive at 1200 Mbps from the TDRS system; see below). Furthermore, it solves some of the most vexing problems involved in designing a general purpose multiprocessor for mainstream commercial applications.

Major computer manufacturers are currently exploring multiprocessor architectures for commercial applications, and are finding the conventional answer of bus-based, cache-coherent

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architectures unattractive, due both to the difficulty of designing cache coherent machines using today's most powerful processors, and in the inherent non-scalability of such designs. These problems are exacerbated by the ability of current super-scalar processors to issue multiple instructions per clock cycle, and thereby individually consume most of the bandwidth of a bus.

Although the simple bus-based Virtual Port Memory architecture is unsuited for such applications, related GMMP (global memory-message passing) architectures have adequate processor-memory bandwidth and don't require cache coherency, thus making such GMMP architectures quite attractive for scalable high-performance multiprocessors.

IBM, Convex (the leading manufacturer of "mini-supercomputers"), and Solbourne (a leading source of RISC multiprocessor server machines) have expressed interest in GMMP architectures for future multiprocessor products.

2.3.2 Related Contributions

Our basic research into the uses of video RAM (VRAM), with its independent random-access and sequential-access ports [42], found application in multiprocessors capable of handling high-rate I/O [43]. An opportunity to evaluate this technique was available in a NASA program seeking to identify architectures capable of processing TDRSS packets which arrive at the White Sands Ground Terminal over four concurrent 300 Mbps channels.

We developed a design in which the high-rate data is pre-processed by special-purpose I/O controllers to perform frame synchronization, error correction and related bit-level functions, and is then loaded into the VRAM main memory of a modified VPM machine through the VRAM sequential access ports, whose bandwidth significantly exceeds even the 1200 Mbps figure. General purpose processing elements then process packet headers and route the packets to terrestrial links by normal accesses via the VRAM random access port, and send messages to outbound I/O controllers which read processed packets out through VRAM sequential ports for terrestrial transmission.

Other research projects in multiprocessor hardware design include a VLSI address translation cache device [44,45] and a VLSI implementation of a virtual memory page replacement algorithm [46]. In addition, we designed and evaluated a novel CPU architecture that tags all instructions and operands to ensure data integrity and correct program operation [47].

A technique called "Working Set Prefetching" [48] was developed that improves multiprocessor performance by eliminating redundant cache line fetches over system buses. (Further development of this technique is the subject of a proposal to the

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Strategic Defense Initiative Organization.)

2.3.3 The ARGOS Operating System

Our experimental GMMP operating system ARGOS (A Research GMMP Operating System) was implemented both to support the evaluation of the Virtual Port Memory architecture, and to explore the implications of supporting message passing (with private address spaces) on a global (shared) memory machine [49, 50, 51, 52]. The performance evaluation discussed above used the actual Local Agent (kernel) message passing code. Some interest has been expressed in our operating systems work by industrial researchers, and one of the students who implemented ARGOS was hired by IBM's workstation division to continue to work on novel operating systems.

2.3.4 Parallel Architecture Research Lab

The Parallel Architecture Research Laboratory (PARL) was established under this grant to provide a facility for designing, building, programming, and evaluating multiprocessors. ARO funding has achieved significant leverage through subsequent equipment grants from leading computer manufacturers, including Hewlett-Packard, Tektronix, and Advanced Micro Devices.

In PARL, we have established a unique facility for acquiring and analyzing computer address traces. Simulation using such traces is a standard technique for evaluating new concepts in computer architecture under realistic workloads. Our facility includes a dedicated Unix workstation (with a CISC CPU) which is instrumented for collecting *complete* traces (including operating system and interrupt activity), a real time trace filter for compressing traces and extending the coverage of finite trace buffers, a data acquisition system capable of storing 512K to 1 million samples per acquisition, and a wide variety of trace analysis and simulation programs. The prototype Virtual Port Memory machine, as well as other parallel machines on campus, serve as sources of multiprocessor traces.

An address trace compaction module was built to expand the length of address traces we can acquire with our DAS-9200 from 128K references to 1M references, which crosses the threshhold for statistical usefulness in many memory hierarchy simulations. Following this, a real-time trace filter was built [53], which can facilitate the collection of virtually unlimited-length traces by reducing the average trace data rate to within the bandwidth of a local area network, allowing the use of mass memory to store traces rather than expensive static RAM (which is necessarily of limited capacity).

2.3.5 Performance Modeling and Analysis

One of the first products of this new facility is a new model

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of the cache miss inter-arrival process. Analysis of traces from the SPEC benchmark suite (on both CISC and RISC workstations) suggests that this process may be well modeled as a random process with inverse-Gaussian inter-arrival times [54,55]. We found this model to be significantly more accurate than the usual assumption that cache misses arrive from a memoryless process (e.g., an exponential distribution).

Che-Chi Weng is analyzing traces produced by this facility to develop a model of instruction access patterns, which can be used to produce synthetic programs for exercising a wide range of computer system models. This workload characterization research is expected to make a valuable contribution to the field of multiprocessor performance modeling, and was discussed enthusiastically by a number of the attendees at the 1991 SIGMETRICS conference.

In the final year of the grant, a technique for predicting the performance of parallel systems was designed that can combine performance results from separately evaluating parallel algorithms and architectures into a prediction of how well particular codes will run on particular machines [56]. (Continuation of this project is the subject of a pending proposal to ARO.) Ultimately, this technique could lead to an "architectural spreadsheet" that allows a system integrator to tune a program and an architecture -- with real-time feedback -- to obtain peak performance before hardware actually exists.

2.4 Vision Systems/Intelligent Control

The control systems research focused on the development of adaptive structures and control concepts for modeling, designing and evaluating multisensor vision control systems. The first part of the research focused on the development of system structures and models to fuse multisensor scene information. The second part was concerned with the development of intelligent controller structures for controlling highly non-linear, difficult to model processes. The major accomplishments of these research efforts are:

*   Development of a system structure and model for fusion of multisensor scene information to perform scene interpretation and understanding for intelligent control decisions [57,58]. A layered and modular hierarchical structure for the intelligent controller [59] was developed and several modules in the different layers of the control structure were developed. The major modules developed for the control structure are:

    ✓ A blackboard Relational Data Base Management System (RDBMS) Structure for handling and organizing a large

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number of sensor reports [58,59,60,61].

✓ Sensor information fusion modules based on RDBMS concepts for scene interpretation and understanding under uncertainty [62,63,64].

✓ Multispectral fast object recognition systems for improved performance and reliability [58].

✓ Sensor performance evaluation and adaptive sensor selection based on consensus and recent performance evaluations [65,66].

✓ Data association for trajectory estimation and tracking [67,68].

✓ Robust distributed multisensor data fusion that combines the strengths and minimizes problems of serial and parallel approaches [69].

* Development of a test-bed for designing and evaluating non-classical control techniques for highly non-linear, difficult to model plants [70]. A vision control system for remotely backing a tractor-trailer in a constrained space was implemented. The system has a replaceable controller for evaluating different controller approaches. Three intelligent control techniques were developed to solve the trailer back-up problem. These are:

✓ K-Nearest neighbor controller using neural networks [10].

✓ Rule-Based Expert system controller [70].

✓ State Partitioning variable structure controller [70].

2.4.1 Multisensor Scene Interpretation and Understanding

Research was focused on the development of a system structure and model to fuse multisensor scene information for intelligent control decisions [57]. A layered and modular distributed hierarchical structure for the intelligent controller was developed [59]. The control structure is comprised of three layers. The primary layer (core) does the high level decision making and performance evaluation. The secondary layer performs data fusion, scene interpretation and reduction of dimensionality. This layer also provides a communications link between the primary and tertiary layers. The tertiary layer is responsible for low-level signal processing (sensors and actuators) and sensor characterization. These layers are made up of modules that perform specific tasks assigned to the different layers. This control structure organizes a large number of sensor reports in a

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blackboard Relational Data Base System to facilitate management and operation. Under this structure, sensor information fusion, scene interpretation and understanding, and control decision were implemented as relational operators operating on the appropriate relations (tables). A set of operators in the lower layers operates on relations formed from the incoming sensor reports to produce new relations to be operated on by the next layer of operators. This process is repeated in each layer until an intelligent control decision is reached. The resulting structure provides a flexible means for incorporating redundancy and allows different schemes to accomplish the same task thus increasing system reliability.

A set of operators were developed to perform several tasks at different levels of the hierarchy. In the area of object recognition for scene interpretation, two 2-D object recognition systems were developed [60,61]. A robust multispectral global object recognition system [58] and a fast partially occluded object recognition system [71,76]. Both of these systems were based on Normalized Interval Vertex Descriptors [72]. In the area of scene interpretation, a set of relational operators for fusing numerical and symbolic information under uncertainty was developed [62,63,64,73]. These operators are based on concepts from the Dempster-Shafer's Theory of Evidence [11]. Using "confidence factors", sensor consensus, and sensor performance history, an adaptive sensor selection and sensor performance evaluation system was developed [65,66]. A new technique for distributed multisensor data fusion was also conceived [69]. This idea combines the strengths and minimizes problems associated with serial and parallel approaches for distributed data fusion. In the area of data association and tracking, several modules were developed. Starting from the standard Kalman filter techniques for reference, to faster and more sophisticated non-statistical techniques [67,68].

In an effort to tie research findings to a more realistic implementation of a multisensor control system, a computer simulation model of the Transportable Telemetry Acquisition System (TTAS) of the WSMR Multisensor Tracking System was also developed [74].

2.4.2 Intelligent Controller Structures

The second part of the control system research was concerned with the development of intelligent controller structures for controlling highly non-linear, difficult to model processes [70]. Designing controllers for highly non-linear processes is among the most challanging and difficult of control problems. Starting from the fact that a "good" model is, in most cases, difficult to obtain. Even if such a model is obtained, designing and implementing an actual controller based on the model remains an even more significant problem. Most multisensor control systems

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fall into this category. Most of these types of controllers are also goal oriented, making the development of an intelligent controller a natural step for handling these types of situations. One of the main drawbacks of intelligent controllers is their lack of generality, that is, they are in most cases application dependent. For this reason, we defined a problem that encompasses most of the previously mentioned constraints. Due to its relevance in the current literature, the problem selected was the evaluation of the controllers used for backing a tractor-trailer in a constrained space [75]. The goal of each controller evaluated is to back a tractor-trailer to a loading dock independently of the trailer load and/or the parking lot conditions. Goal orientation and model independence are the driving forces behind this research effort. With these ideas in mind, we developed a suite of intelligent controllers to carry out the task. They included: a k-nearest neighbor network controller [10], a rule-based expert system controller [70], and a state partitioning variable structure controller [70].

The k-nearest neighbor controller was implemented using a "neural-like" hierarchical structure. The overall goal of the system (backing to the dock) was subdivided into simpler goals with associated secondary controllers. The goal of an individual secondary controller was to take the system closer to the overall goal. The controllers were trained using data derived from a simplified computational model of 18-wheel tractor-trailer rig. In the initial two level implementation, the top level, called the supervisor, assesses the control situation and selects the appropriate controller in the second level to control the system. The controllers in the second level are very simple k-nearest-neighbor (KNN) controllers that perform relatively simple tasks. To demonstrate the concepts, an "intelligent" vision guided system was developed to remotely park a tractor-trailer in a constrained region. This controller requires only eight control points and a rule-based expert system supervisor. The control structure adapts well to random effects caused by measurement and vehicle control errors and is suited for nonlinear and unstructured control problems that are difficult to model. One of the major accomplishments of this approach is the reduction of the complexity of the lower level controllers, since they are designed to control the system in very simple operating modes. For this particular implementation the secondary controllers consisted of only nearest neighbor control elements. This controller was also successfully used to balance a inverted pendulum.

A Rule-based expert system controller was also implemented to for the trailer backing problem. Knowledge gained from an experienced tractor-trailer driver was converted to IF-THEN rules to back the truck to the dock. These rules were stored in a rule database and later used to guide the truck under the expert system control.

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A general approach was developed for this type of control problem. The approach termed "state partitioning control" involved the idea of a multiple-level variable structure controller where the control problem (control surface) is partitioned into simpler control problems that can be solved with simpler controllers. The top level, the supervisor, assesses the control situation selecting the appropriate controller in the secondary levels to control the system. The flexibility of this approach is that any controller, either the supervisor or any of the secondary controllers, can be implemented in a different manner depending on the control situation (rule-based, neural networks, classical controller, non-linear controller, etc.). For this particular problem a two-level controller was implemented. The supervisor and the secondary controllers were implemented using rule-based expert systems. The big difference between this implementation and the previous global expert system lies in the number and complexity of the rules to control the truck. In the global case a larger number of more complicated rules are required since there are more complex control situations. In the state partitioning case, the control situations are much simpler (forward, backwards, etc.) therefore a smaller number of simple rules are required.

Another very important drawback of intelligent controllers is the lack of mathematical tools for performance analysis and comparisons. To overcome these difficulties, we developed a test-bed for implementation and development of non-classical control techniques. A vision control system to control the backing of a "pseudo-real" truck was implemented. This system was designed with a modular replaceable controller. The system has the capability of controlling the plant with different controller schemes for performance comparisons. The experiments consisted of backing a remotely operated toy truck and trailer controlled by a personal computer under the guidance of a vision system using the various controller modules.

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[35] "A Multiple Target Rotation and Scale-Invariant Optical Recognition System That Uses Time-Sequenced Correlation Plane Filtering," Ph.D. Dissertation, Thomas Walsh, New Mexico State University, May 1990.

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[39] "Application of the Mathematical Theory of Evidence to the Image Cueing and Segmentation Problem," <u>Proceedings of SPIE 1990 Symposium on Infrared Optical Systems</u>, Orlando, FL, April 1990.

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IV. PERSONNEL SUPPORTED AND DEGREES GRANTED

Major Investigators	Research Area
Flachs, G. M.	Image Processing
Giles, M. K.	Optical Processing
Jordan, J. B.	Image Processing
Ludeman, L. C.	Image Processing
Johnson, E. E.	Computer Architecture
Johnston, J.B.	Computer Architecture
Parra-Loera, R.	Control Systems
Thompson, W.E.	Control Systems
Kazda L.F.	Control Systems

Doctoral Students	Dissertation
Carlson, Jeffrey	"Decision-Making Complexity With Applications in Electronic Vision," Ph.D. Granted.
Beer, Cynthia	"Tie Statistic and Application to Texture Recognition," Ph.D. Granted.
El-Ghazawi, Tarek	"A Motion Detection Multiprocessor Computer System," Ph.D. Granted.
Scott, David	"The K-nearest Neighbor Statistic with Applications to Electronic Vision Systems," Ph.D. Granted.
Choe, Howan	"A comparative analysis of statistical, fuzzy, and artificial neural pattern recognition techniques," Ph.D. Granted
Walsh, Thomas	"A Multiple Target Rotation and Scale-Invariant Optical Recognition System That Uses Time-Sequenced Correlation Plane Filtering," Ph.D. Granted
Antosik, R.	"Pattern Recognition with Markov Probabilistic Models," Ph.D. Granted
Draayer, Brett	"Correlation-based optical recognition via Bayesian classification of composite distributions," Ph.D. Granted
Tao, Chin-Wang	"Pseudo K-means and Fuzzy Algorithms for Detection, Classification and Tracking," Ph.D. Granted
Rasolian, H.	"An Experimental Data Fusion Model for Multi-Sensor Systems," Ph.D. Granted

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Doctoral Students	Dissertation
Kittur V.	"Data Association Using Multi-Sensor Fusion," Ph.D. Granted
Clark, N.	Current Ph.D. Student: Electro-Optics
Zhonghar,B.	Current Ph.D. Student: Image Processing
Khurrum, M.	Current Ph.D. Student: Image Processing
Hwang, W.	Current Ph.D. Student: Control
Ma, Ding	Current Ph.D. Student: Architecture
Moore, R.	Current Ph.D. Student: Architecture
Weng, C.	Current Ph.D. Student: Architecture

M.Sc. Students

Caudle, W.	M.S. Granted: Image Processing
Salem, F.	M.S. Granted: Architecture
Ajit Salvi	M.S. Granted: Control
Johnson, W.	M.S. Granted: Architecture
Jackson, R.	M.S. Granted: Architecture
Bock, B.	M.S. Granted: Electro-Optics
Cravatt, J.	M.S. Granted: Electro-Optics
Shen, L.	M.S. Granted: Electro-optics
Baker, T.	M.S. Granted: Electro-optics
Kast, B.	M.S. Granted: Electro-optics
Smith, J.	M.S. Granted: Electro-optics
Bock, B.	M.S. Granted: Electro-optics
Cravatt, J.	M.S. Granted: Electro-optics
Draayer, B.	M.S. Granted: Electro-optics
Chaapel, C.	M.S. Granted: Image Processing
Zhang, M.	M.S. Granted: Architecture
Schieber, C.	M.S. Granted: Architecture
Lopez, T.	M.S. Granted: Image Processing
Crandall, C.	M.S. Granted: Electro-Optics
Gaughan, P.	M.S. Granted: Image Processing
Corelis, D.	M.S. Granted: Control
Singh, S.	M.S. Student: Image Processing
Lumeyer, M.	M.S. Granted: Architecture
Schuler, K.	M.S. Granted: Architecture
Clark, N.	M.S. Granted: Electro-Optics
Powell, K.	M.S. Student: Electro-Optics

Undergradate Students Supported

Powell K.	B.S.	Electrical and Computer Engineering, Granted
Carhart, G.	B.S.	Hourly
Billings, P.	B.S.	Electrical and Computer Engineering, Granted
Giles, T.	B.S.	Hourly
Baca, M.	B.S.	Electrical and Computer Engineering, Granted
Flores, A.	B.S.	Electrical and Computer Engineering, Granted

V.   GOVERNMENT/INDUSTRIAL CONTACTS

An important goal of the research project is to transfer new concepts and techniques to the Army laboratories and industry. Often this requires the investigators to assist the laboratories implement the concepts in their applications. The feedback, however, is important in evaluating and motivating the basic research. Some important technology transfer activities related to the sponsored research are:

* Several members of the image processing and electro-optical research groups have worked with Duke University Engineering Research Center for Emerging Cardiovascular Technologies on several joint projects for applying digital and optical signal processing techniques to cardiovascular problems. The effort is a collaborative real-time signal processing research in automatic implantable defibrillators and ultrasonic blood flow measurements.

* The image processing research group assisted the Atmospheric Science Laboratory's Target Contrast Characterizer project team in implementing a near real-time complexity measuring system for IR signature analysis. The system is being used to investigate and characterize atmospheric and battlefield conditions as they affect IR target detection equipment.

* The image processing research group is assisting the Instrumentation Division at White Sands Missile Range design a near real-time film reading processing system using the results of the research sponsored by this research contract.

* The image processing research group together with the NMSU entomology department are working to develop an electronic vision system for automatic assessment of cotton insect pest densities.

* The electro-optical research group is applying the N-dimensional tree search methodology to the output response data from the acousto-optic image correlator at Sandia National Laboratories.

* The electro-optical research group demonstrated the feasibility of using both joint transform correlators and acousto-optic correlators to measure flow vectors in medical ultrasound images obtained from Duke University.

* The architecture research group assisted several government and industrial organization evaluate the Virtual Port Memory Multiprocessor Architecture relative to their applications.

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Technical contacts made during the grant are:

NAME	ORGANIZATION	APPLICATION
Tom Reader	U.S. Army Vulnerability Assessment Laboratory	Multispectral Evaluation
Robert Green Henry Stephenson	WSMR Instrumentation Div.	Target Tracking and Fusion
Terry Stalker Fred Dickey	Sandia National Labs Albuquerque	Autonomous Vehicles
Jeffrey Carlson	Sandia National Labs	Tracking Applications
Don Gregory	MICOM, Huntsville	Missile Systems
Jim Florence	Texas Instruments	Phase Modulation
Phillippe Backer	IBM Advanced Workstations	Operating Systems
James Dillinger	IBM Advanced Workstations	Virtual Port Arch.
James Kahle	IBM Advanced Workstations	Virtual Port Arch.
Lynn West	IBM Advanced Workstations	Virtual Port Arch.
Robert Gallegos	Bell Laboratories	Multiprocessor OS
Karl Whiting	Convex Computer Co.	Virtual Port Arch.
Philip Fleming	AT&T	Performance Analysis
Blaine Gaither	Amdahl Corp.	Performance Analysis
Rajeev Jog	Hewlett-Packard	Performance Analysis
Dan Welter	Compaq Computer Corp.	Performance Analysis
Adrian King	Sandia National Labs	Parallel Computing
Stephen Cook	Australia	Automated Communication
Robert Desourdis	Science Applications	Automated Communication
Simon Rosenblatt	Army Info Systems Eng.	Automated Communication
Lars Stromberg	Sunair Electronics	Automated Communication
Wendell Watkins	Atmospheric Sciences Lab.	IR Image Complexity

Ron Hayslett Joe Ambrose	WSMR Instrumentation Div.	Automatic Film Reader
Bill Ross	Litton Data Systems Van Nuys, CA	Phase-Only Filtering
Greg Trahey	Duke University	Biomedical Research
Tom Cathey Mark Freeman	University of Colorado	Optical Computing Center